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Evaluation of drawability of thin aluminium alloy sheets

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ABSTRACT

For many years, aluminium alloy sheets have been used mainly in aircraft production, but also in the construction and consumer industries, precisely because of their low weight and good corrosion resistance. In recent years, these sheets have been used in the construction of car bodies. For this purpose, it is necessary to know their suitability for deep drawing. The paper deals with the determination of the drawing limit coefficients for four types of aluminium alloy sheets. One sheet is made of $AlMgSi_1$ alloy and three sheets are made of $AlMg_3$ alloy. The uniaxial tensile test was used to evaluate the drawability of the sheets and the determination of the drawing limit coefficient was carried out by an earring test.

Keywords *- aluminium alloys, drawability, drawing limit coefficient*

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I. INTRODUCTION

The formability of a material is defined by the ability to overcome a permanent change in shape without breaking the material under specific technological conditions that allow the product to be manufactured of the desired dimensions, shape and properties. The main property for good formability is the elongation of the material, which is given by the amount of deformation until breaking under precisely defined conditions (stress state, strain rate, temperature) [1, 2].

Material properties that have direct or indirect influence on the formability and quality of the product are strength and ductile characteristics (yield strength, tensile strength, elongation and contraction), relative and logarithmic deformation, strain hardening exponent, normal anisotropy coefficient and other deformation performance indicators for certain conditions of plastic deformation implementation (overall formability index, plasticity stock index, tensile strength / yield strength ratio, formability index, sheet formability aspect) [3-5].

Aluminium alloys have significantly better properties compared to pure aluminium. They are currently used mainly in the automotive and aerospace industries [6-8]. The aim of the paper was to determine the limit deformations of aluminium sheets when drawing of the cylindrical cups. The mechanical properties of the examined sheets were determined by a uniaxial tensile test. The tensile test was used to evaluate the drawability of the sheets and the determination of the drawing limit coefficient was carried out by an earring test.

II. EXPERIMENTAL MATERIALS AND METHODOLOGY

The sheets from aluminum alloys where used for the experiment to evaluate the formability. The tested sheets 1 with thickness 1.00 mm and 2, 3 and 4 with thickness 0.80 mm are described in Table 1.

Table 1 Evaluated aluminum alloys

Designation of evaluated materials	Description	Designation of the material according to EN AW	Designation of the material according to DIN
1	After solution annealing and subsequent aging	EN AW 6082	$AlMgSi_1$
2	Deformation lightly hardened	EN AW 5754	$AlMg_3$
3	Deformation hardened and partly annealed 1/4 hard	EN AW 5754	$AlMg_3$
4	Deformation hardened and partly annealed 1/2 hard	EN AW 5754	$AlMg_3$

Uniaxial tensile test

Uniaxial tensile test was carried out on the device TIRA test 2300 (Fig. 1). The test conditions and the shape of the sample indicate standards STN EN 10002-1+AC1 and STN 42 0321. Samples were taken for a tensile test to determine mechanical properties of the material under zero-, 45-, and 90-degree angle in relation to the direction of rolling.

From uniaxial tensile test there were measured and calculated mechanical properties – yield strength, tensile strength and elongation.

Earring test

The formability of sheets is often characterized by a drawing limit coefficient, which is determined by an earring test and its value for a flat-bottomed cylindrical cup is given by:

$$m = d / D_{0m} \qquad (1),$$

where: d – cup diameter [mm],

D_{0m} – the largest diameter of the blank at which the blank was not damaged [mm].

The drawing limit coefficients obtained by the earring test are characterized as technological parameters of sheet pressability. They are determined by specific technological conditions of pressing, mainly by holding force, lubrication, varying friction ratios in individual parts of the tool due to the radius of curvature of the tool active parts, resp. by holding force. The drawing limit coefficient is the ratio of the diameter of the cup to the diameter of the blank at which the bottom of the cup is not damaged.

The earring test was performed to determine the drawing limit coefficient of the experimental materials. In the test, from the circular blanks of diameters D_{0max} = 58.0 mm; 55.0 mm; 52.0 mm and 50.0 mm were drawn cups. From each diameter, 3 blanks were made for all examined materials.

In Fig. 1 a) is a test tool used in the earring test and cups made of material 3 (Fig. 1 b).

a) b)

Fig. 11 Tool for earring test (a), cups from material 3 (b)

III. RESULTS AND DISCUSSION

The measured values of mechanical properties from the uniaxial tensile test with respect to the rolling direction are given in Table 2.

Table 2 Mechanical properties values of examined materials

Tested material	**Direction of rolling [°]**	**Mechanical properties**						
		$R_{p0.2}$ [MPa]	**R_m [MPa]**	**A_{80} [MPa]**	**r [-]**	**r_m [-]**	**n [-]**	**n_m [-]**
1	0	314	342	13.7	0.528	0.564	0.087	0.086
	45	308	337	14.2	0.657		0.086	
	90	313	341	12.0	0.509		0.086	
2	0	146	231	19.6	0.655	0.827	0.282	0.283
	45	136	220	26.1	1.104		0.283	
	90	137	221	25.4	0.723		0.283	
3	0	185	270	16.2	0.945	1.163	0.192	0.195
	45	175	261	20.8	1.560		0.199	
	90	180	257	19.2	0.986		0.193	
4	0	87	132	4.8	1.337	1.646	0.128	0.129
	45	86	131	4.0	1.978		0.130	
	90	98	142	6.1	1.622		0.129	

When evaluating the drawability of the sheets, we use the average normal anisotropy coefficient r_m and the average strain hardening exponent n_m. The quality of the sheets can be evaluated based on the Lileth diagram shown in Fig. 2.

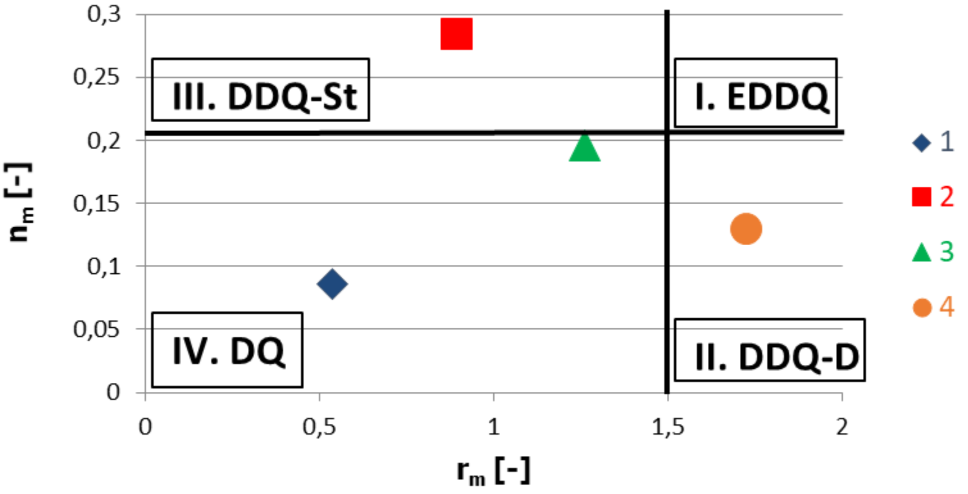

Fig. 2 Drawability according to the combination of values r_m a n_m

From the point of drawability we evaluate the examined sheets as follows:

- material 1 ($n_m = 0.086$; $r_m = 0.564$) → DQ = material is not suitable according to deep-drawing,
- material 2 ($n_m = 0.283$; $r_m = 0.827$) → DDQ-St = material is suitable where the dominant deformation is biaxial tension,
- material 3 ($n_m = 0.195$; $r_m = 1.163$) → DQ = material is not suitable according to deep-drawing,
- material 4 ($n_m = 0.129$; $r_m = 1.646$) → DDQ-D = material is suitable where the dominant deformation is pressure.

The drawing limit coefficient of experimental materials was determined by earring test. Table 3 shows the resulting maximum drawing forces of the individual blank diameters and the forces that broke the material 2, 3 and 4. When drawing the material 1 (1.00 mm thick), it was not possible to produce a cup due to the drawing tool being produced such that the drawing gap was less than the thickness of the drawn material. Thus, at the beginning of the drawing, the wall of the cup was thinned and, as a result, the cup was damaged. Cups from this material could not be drawn even with smaller blanks diameters. For this reason, this material was not further evaluated at the earring test.

Table 31 Maximum drawing forces of tested materials during the earring test

Material	**Values**	**Blank diameter D_0 [mm]**	**Average drawing force F_{max} [kN]**	**Cup condition**
2	measured	50.0	11.0	not damaged
2	measured	52.0	12.2	not damaged
2	measured	55.0	11.4	not damaged
2	measured	58.0	13.1	not damaged
2	calculated	68.4	15.8	damaged
3	measured	50.0	11.4	not damaged
3	measured	52.0	13.9	not damaged
3	measured	55.0	12.6	not damaged
3	measured	58.0	14.8	not damaged
3	calculated	67.3	18.9	damaged
4	measured	50.0	6.6	not damaged
4	measured	52.0	7.8	not damaged
4	measured	55.0	7.1	not damaged
4	measured	58.0	8.5	not damaged
4	calculated	65.6	10.3	damaged

Fig. 3 shows the graphical representation of the determination of the blank limit diameter for material 2.

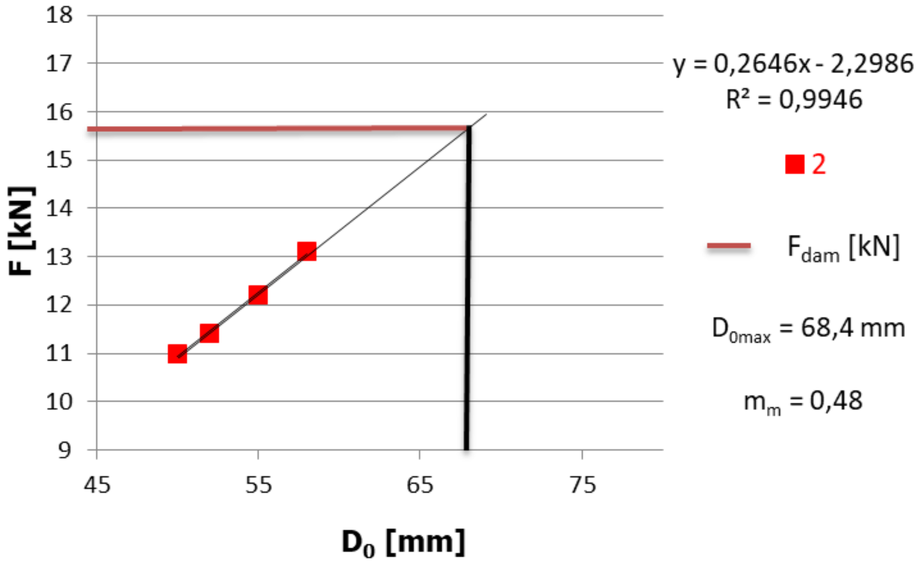

Fig. 3 Determination of the blank limit diameter for material 2

Material 2 breaks at a force F_{dam} = 15.8 kN. The mathematically calculated blank diameter for this material is D_{0max} = 68.4 mm. The drawing limit coefficient is m_m = 0.48.

In Fig. 4 is a graphical representation of the determination of the blank limit diameter for material 3.

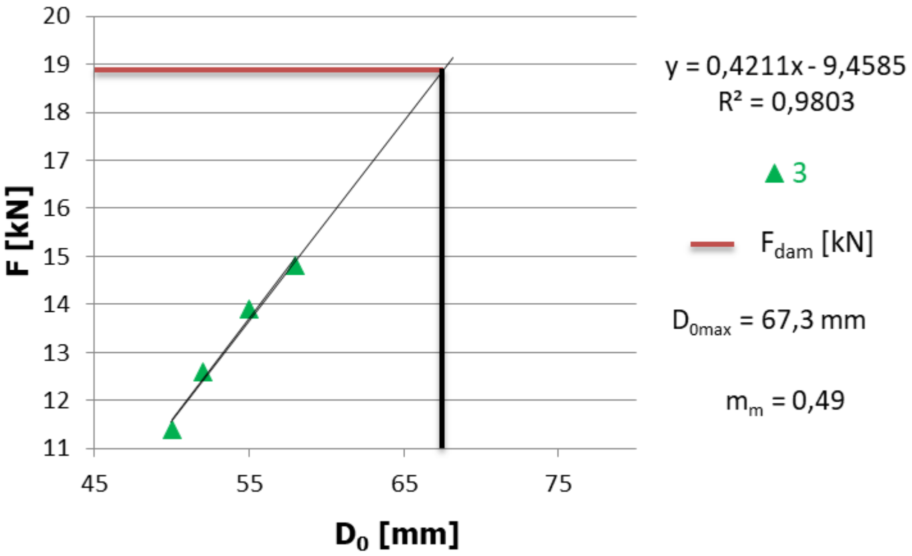

Fig. 4 Determination of the blank limit diameter for material 3

Material 3 breaks at a force F_{dam} = 18.9 kN. The mathematically calculated blank limit diameter for this material is D_{0max} = 67.3 mm. The drawing limit coefficient is m_m = 0.49.

In Fig. 5 is a graphical representation of the determination of blank limit diameter for material 4.

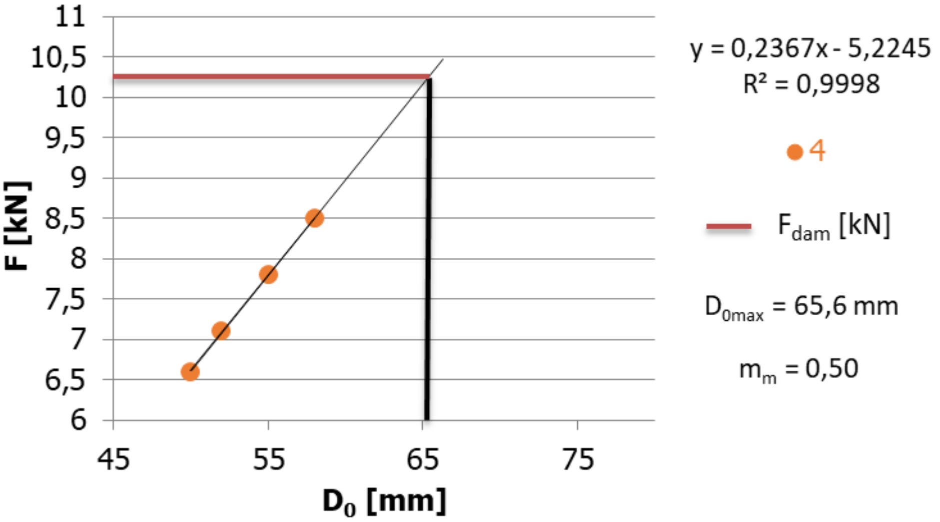

Fig. 5 Determination of the blank limit diameter for material 4

Material 4 breaks at a force F_{dam} = 10.3 kN. The mathematically calculated blank limit diameter for this material is D_{0max} = 65.6 mm. The drawing limit coefficient is m_m = 0.50.

IV. CONCLUSION

The evaluation of the formability of thin aluminium alloy sheets was made based on the results of the uniaxial tensile test and the earring test. The strain hardening exponent values and normal anisotropy coefficients for all examined aluminium alloys sheets were determined from the uniaxial tensile test. Based on these values using the so-called Lileth diagram, the sheets can be divided into four different groups of drawability. According to this classification, two types of sheets are unsuitable for deep-drawing. All four types of sheets can be considered suitable for deep drawing based on the earring test. For all types of used sheets of aluminium alloys, the drawing coefficient m = 0.5 and lower was achieved.

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